Weighted Model Counting Without Parameter Variables

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The Problem of Computing Probability

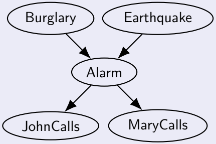
ProbLog

```
0.001  :: burglary.
0.002  :: earthquake.
0.95   :: alarm      :- burglary, earthquake.
0.94   :: alarm      :- burglary, \+ earthquake.
0.29   :: alarm      :- \+ burglary, earthquake.
0.001  :: alarm      :- \+ burglary, \+ earthquake.
0.9    :: johnCalls :- alarm.
0.05   :: johnCalls :- \+ alarm.
0.7    :: maryCalls :- alarm.
0.01   :: maryCalls :- \+ alarm.
```

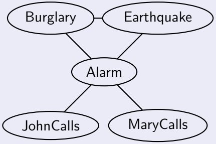
BLOG

```
random Boolean Burglary ~ BooleanDistrib(0.001);
random Boolean Earthquake ~ BooleanDistrib(0.002);
random Boolean Alarm ~
  if Burglary then
    if Earthquake then BooleanDistrib(0.95)
    else BooleanDistrib(0.94)
  else
    if Earthquake then BooleanDistrib(0.29)
    else BooleanDistrib(0.001);
random Boolean JohnCalls ~
  if Alarm then BooleanDistrib(0.9)
  else BooleanDistrib(0.05);
random Boolean MaryCalls ~
  if Alarm then BooleanDistrib(0.7)
  else BooleanDistrib(0.01);
```

Bayesian Network



Markov Random Field



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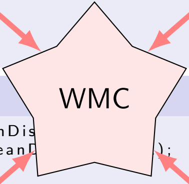
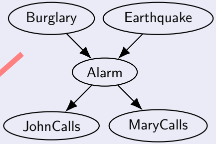
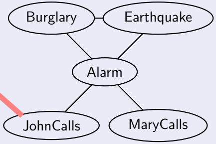


Bayesian Network



Markov Random Field



Weighted Model Counting (WMC)

- Generalises propositional model counting (#SAT)
- Applications:
  - graphical models
  - probabilistic programming
  - neural-symbolic artificial intelligence
- Main types of algorithms:
  - using knowledge compilation
  - using a SAT solver
  - manipulating pseudo-Boolean functions

Example

$w(x) = 0.3,\ w(\neg x) = 0.7,$
$w(y) = 0.2,\ w(\neg y) = 0.8$

$\mathrm{WMC}(x \vee y) = w(x)w(y) + w(x)w(\neg y) + w(\neg x)w(y) = 0.44$

Outline

Outline

Formalising the Intuition from Before

For any propositional formula ϕ over a set of variables X and $p, q \in \mathbb{R}$, let $[\phi]^p_q \colon 2^X \to \mathbb{R}$ be the pseudo-Boolean function defined as

$$[\phi]^p_q(Y) \coloneqq \begin{cases} p & \text{if } Y \models \phi \\ q & \text{otherwise} \end{cases}$$

for any $Y \subseteq X$.

Definition (Pseudo-Boolean Projection (PBP))

A PBP instance is a tuple (F, X, ω), where X is the set of variables, F is a set of two-valued pseudo-Boolean functions $2^X \to \mathbb{R}$, and $\omega \in \mathbb{R}$ is the scaling factor.

From WMC to PBP

The WMC instance has x as the only indicator variable and p, q as parameter variables with weights $w(p) = 0.2$, $w(q) = 0.8$, and $w(\neg p) = w(\neg q) = 1$.

WMC Clause
$\neg x \Rightarrow p$
$p \Rightarrow \neg x$
$x \Rightarrow q$
$q \Rightarrow x$
$\neg x$

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WMC Clause	In CNF
$\neg x \Rightarrow p$	$x \vee p$
$p \Rightarrow \neg x$	$\neg x \vee \neg p$
$x \Rightarrow q$	$\neg x \vee q$
$q \Rightarrow x$	$x \vee \neg q$
$\neg x$	$\neg x$

From WMC to PBP

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WMC Clause	In CNF	Pseudo-Boolean Function
$\neg x \Rightarrow p$	$x \vee p$	$[\neg x]^{0.2}_{1}$
$p \Rightarrow \neg x$	$\neg x \vee \neg p$	
$x \Rightarrow q$	$\neg x \vee q$	$[x]^{0.8}_{1}$
$q \Rightarrow x$	$x \vee \neg q$	
$\neg x$	$\neg x$	$[\neg x]^{1}_{0}$

From WMC to PBP

The WMC instance has x as the only indicator variable and p, q as parameter variables with weights $w(p) = 0.2$, $w(q) = 0.8$, and $w(\neg p) = w(\neg q) = 1$.

WMC Clause	In CNF	Pseudo-Boolean Function	
$\neg x \Rightarrow p$	$x \vee p$	$[\neg x]_1^{0.2}$	$[x]_{0.2}^{0.8}$
$p \Rightarrow \neg x$	$\neg x \vee \neg p$		
$x \Rightarrow q$	$\neg x \vee q$	$[x]_1^{0.8}$	
$q \Rightarrow x$	$x \vee \neg q$		
$\neg x$	$\neg x$	$[\neg x]_0^1$	$[\neg x]_0^1$

Outline

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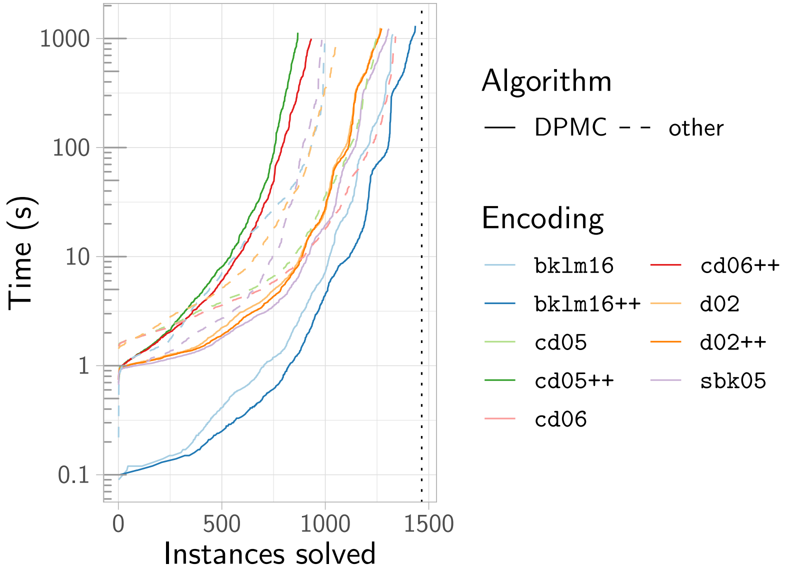
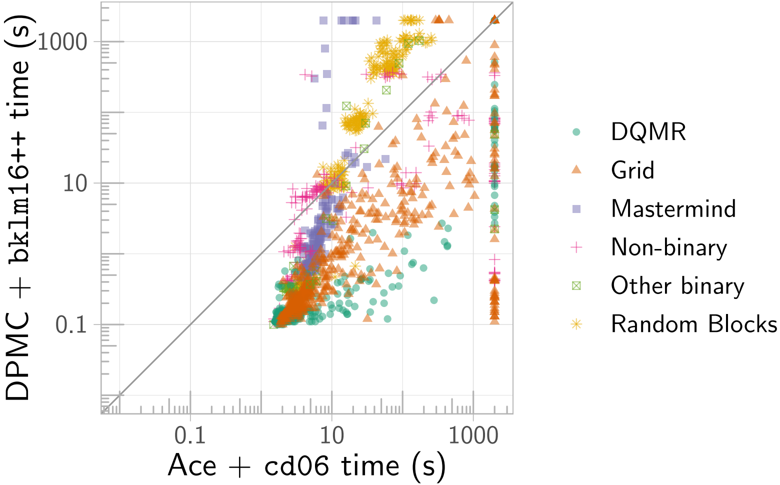
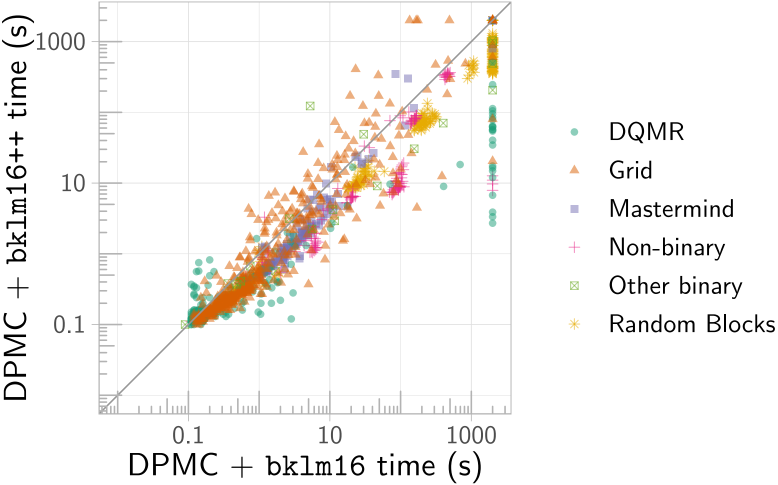
Experimental Results



Experimental Results



Experimental Results



Outline

Summary